Kilo-pixel arrays of TES X-ray microcalorimeters for the International X-ray Observatory (IXO)

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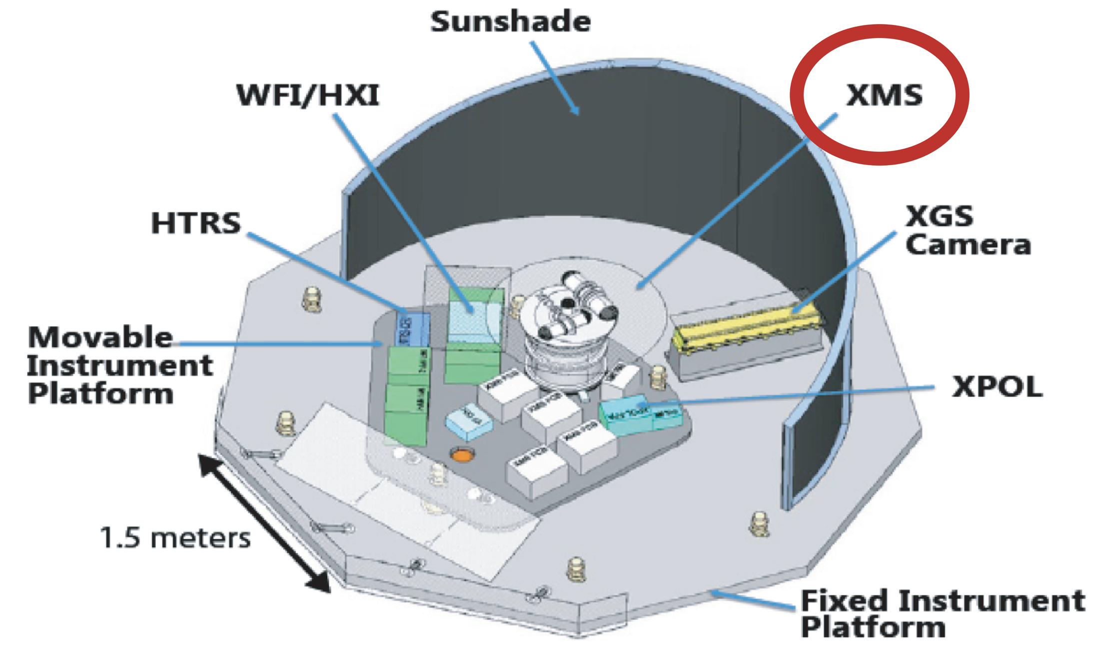
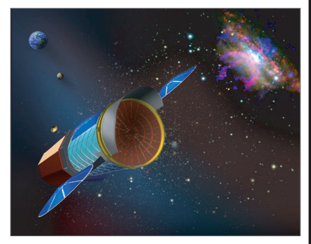


IXO Instruments

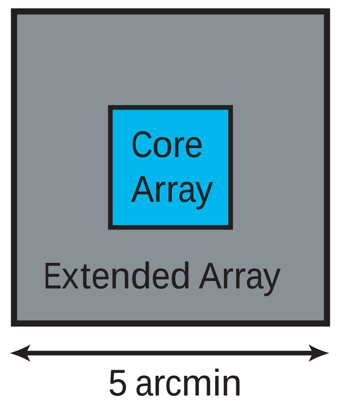
The X-ray Microcalorimeter Spectrometer (XMS) for IXO



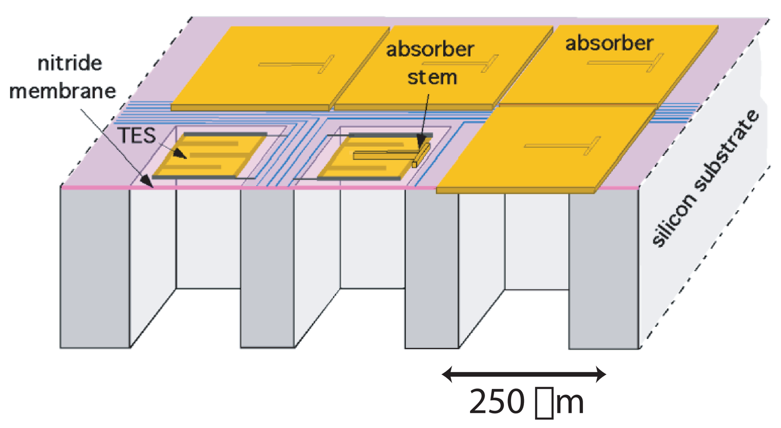
The International X-ray Observatory (IXO) mission is currently being formulated by NASA, the European Space Agency, and the Japanese Aerospace Exploration Agency. One of IXO's primary instruments will be the X-ray Microcalorimeter Spectrometer (XMS), a high-resolution imaging spectrometer with a 5 arcminute field of view and an energy resolution of 2.5 eV at 6 keV. Our team, a collaboration between NASA's Goddard Space Flight Center and the National Institute of Standards and Technology (NIST), is working to develop the detector and read-out technology that will meet the mission's requirements.

XMS Reference Design:

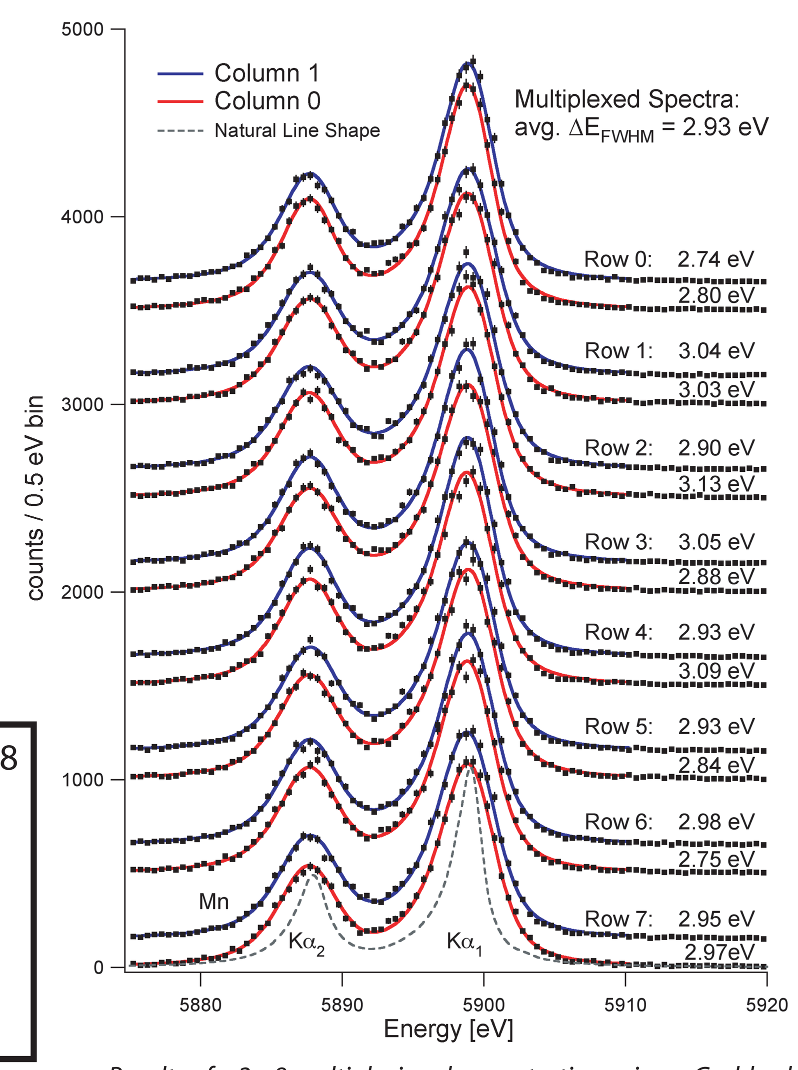
	Core Array:	Extended Array:
Array Size:	40 x 40 pixels	2304 pixels
PIxel Size:	300 x 300 sq. micron	600 x 600 sq. micron
Bandpass:	0.3 – 12 keV	0.3 - 12 keV
Energy Resolution:	2.5 eV at <6 keV	10 eV at <6 keV
Count Rate:	50 cps per pixel	2 cps per pixel



Background and Prior State of the Art

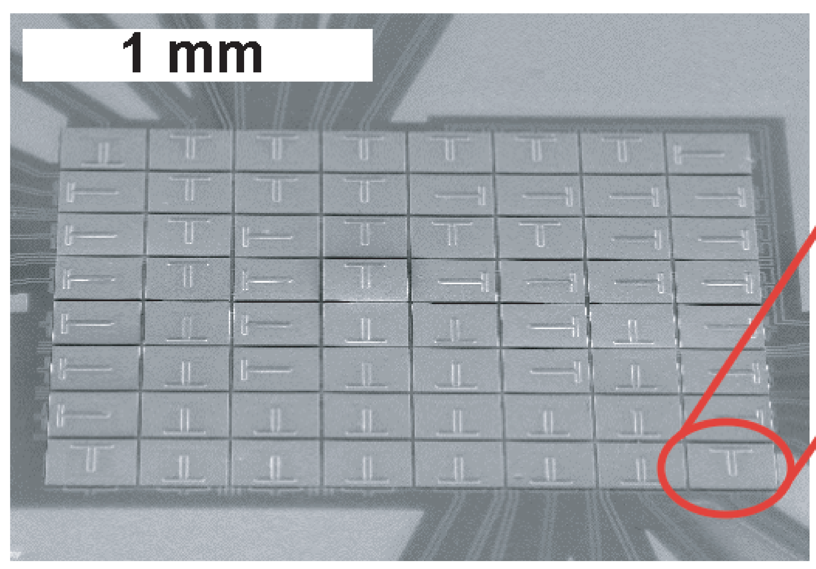


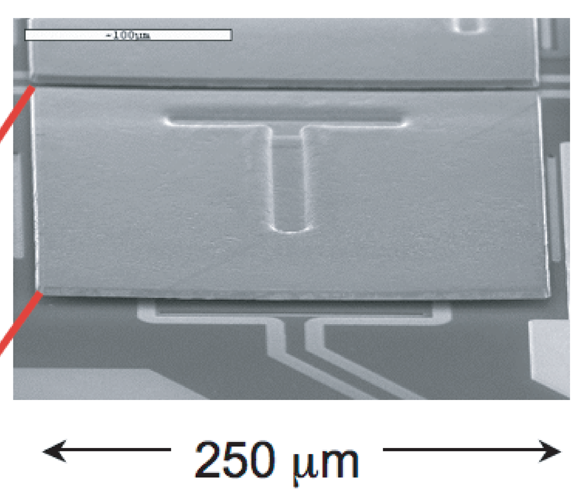
Device Architecture: Our arrays use superconducting transition-edge sensors (TESs). Each TES is made of a Mo/Au bilayer, tuned tuned to a Tc of ~ 90 mK. A microns-thick X-ray absorber overhangs the TES and wiring, and is connected to the sensor at the absorber stem [1,2].



Results of a 2 x 8 multiplexing demonstration using a Goddard array and NIST SQUID multiplexing electronics at NIST.

In 2008 our team successfully demonstrated 8 x 8 TES arrays with Mo/Au TES bilayers on silicon-nitride membranes and Au/Bi overhanging absorbers. These pixels provided 2.3 eV energy resolution at 6 keV. Array uniformity was sufficient for a 2-column by 8-row time-division SQUID multiplexing demonstration [3].





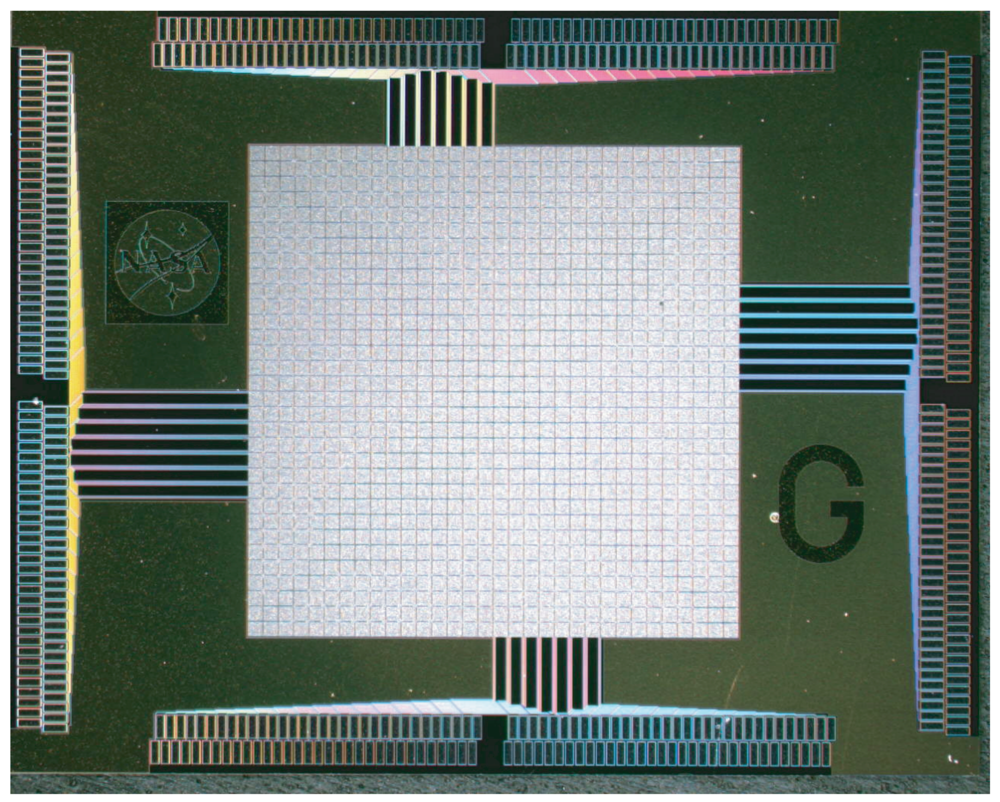
Electron micrograph of a uniform 8 x 8-pixel TES array. The closeup view on the right shows an individual pixel with its absorber hanging over the wiring and substrate.

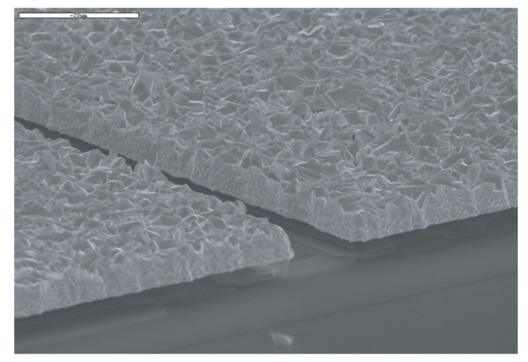
Current Progress

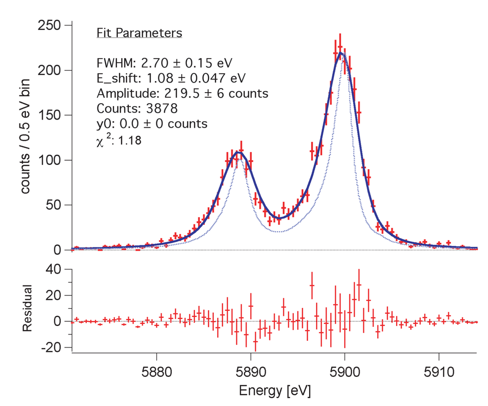
We are currently working to demonstrate kilopixel scale arrays and the associated readout, as a critical step on the path to building a prototype of the XMS core array. The next milestone we are heading toward is a 3-row by 32-column time-division SQUID multiplexing demonstration of pixels from a 32 x 32-pixel array. To extend our technology to kilopixel array sizes and beyond, we need to integrate high-density, low-crosstalk wiring and array-scale heat-sinking into the fabrication process.

32 x 32-Pixel Arrays

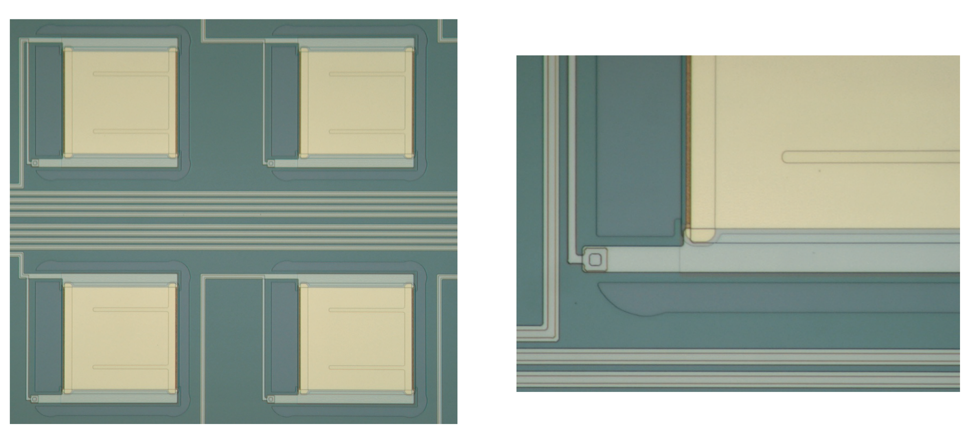
We have completed fabrication of several wafers of 32 x 32 arrays:
- 300 □m pixel pitch
- Two wafers with planar wiring leads
- One wafer with microstrip wiring
  - 256 pixels (25% of the array) wired to pads
  - Interior wiring for1024 pixels included to prove required density


Photograph of 32 x 32 array with microstrip wiring

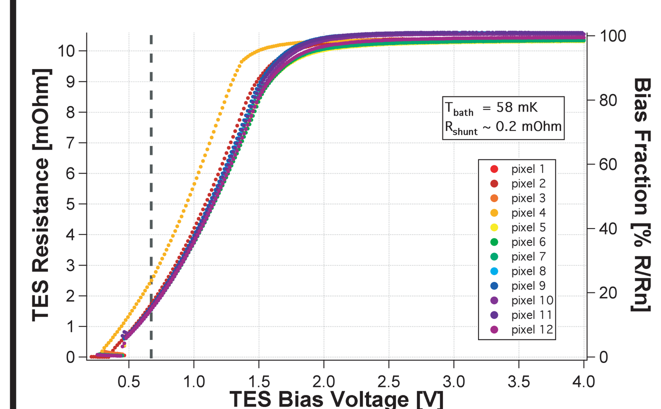

overhanging Au/Bi absorbers on 32 x 32 array


Mn K□ spectrum from one pixel of a 32 x32 array with planar wiring demonstrating 2.7 eV energy resolution

Microstrip Wiring


Photographs of integration of micostrip wiring with a TES array

High-density, low-electrical-crosstalk wiring is achieved with superconducting microstrips (stacked signal and return wires separated by insulating layer). Microstrips are an established technology, but integrating microstrips with the TES process involves depositing an insulator on top of the TES and other changes to the standard process that needed to be developed.



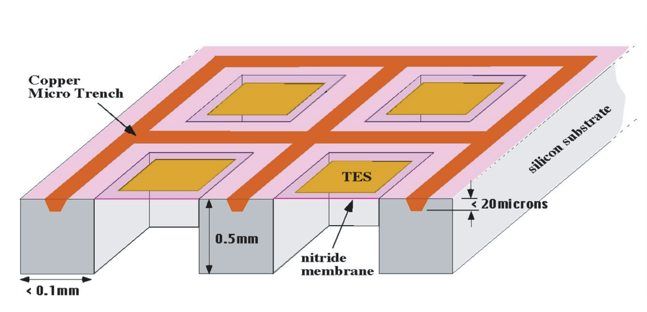
Mesaured uniformity: *TES resistance as a function of bias voltage for 12 pixels on the 32 x 32 array with microstrip wiring. The dashed vertical line indicates a typial operational bias resistance of 15% R/Rnormal. At this voltage bias 11 of 12 pixels are biased identically while the final pixel is biased at 25% R/Rn, which should result in an energy resolution degradation of less than 0.1 eV.*

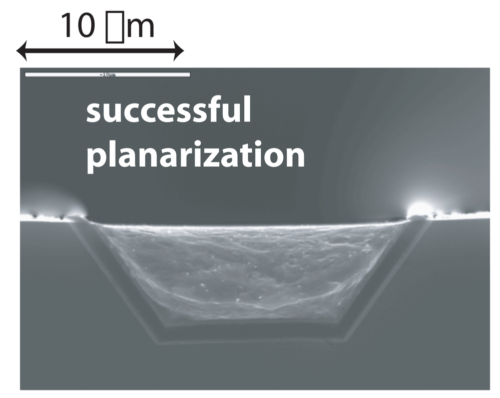
Integrated Heatsinks

The open structure of our TES arrays, in which the silicon substrate is removed under each TES pixel to leave a free-standing nitride membrane, does not adequately conduct heat from the interior of the array to the edges where it is heat sunk.

To increase conduction to the bath we are:

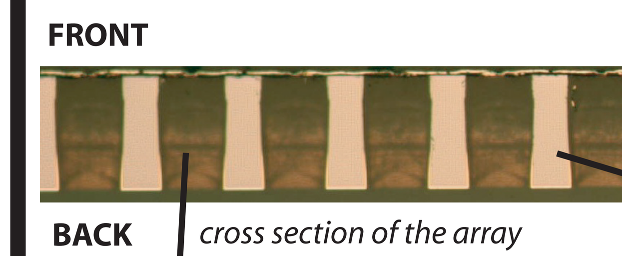
1) developing a robust process for producing copper-filled microtrench heatsinks that is compatible with the TES array process;





schematic view of microtrench heatsinks and cross-section showing planarization

2) developing an improved backside heatsinking process in which copper is deposited on the sidewalls of the silicon wells beneath each pixel.

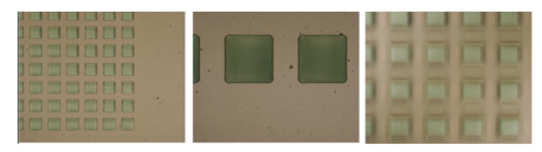


cross section of the array

The Cu extends ~40% up each sidewall

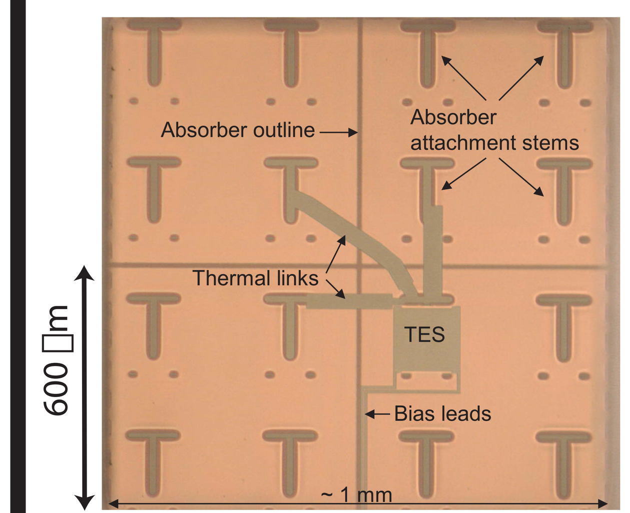
Si frame coated by ~6 □m of copper

We have successfully implemented a new angle-evaporation apparatus that allows all four sidewalls to be coated in Cu without getting Cu on the backs of the membranes and without breaking vacuum.

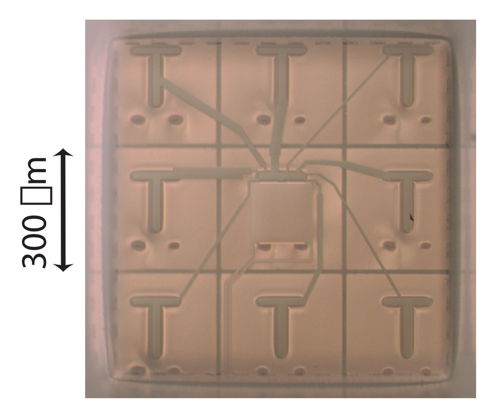

Images from the backside of the array. The Cu coats the back of the array and the sidewalls but does not get on the membrane (see right image).

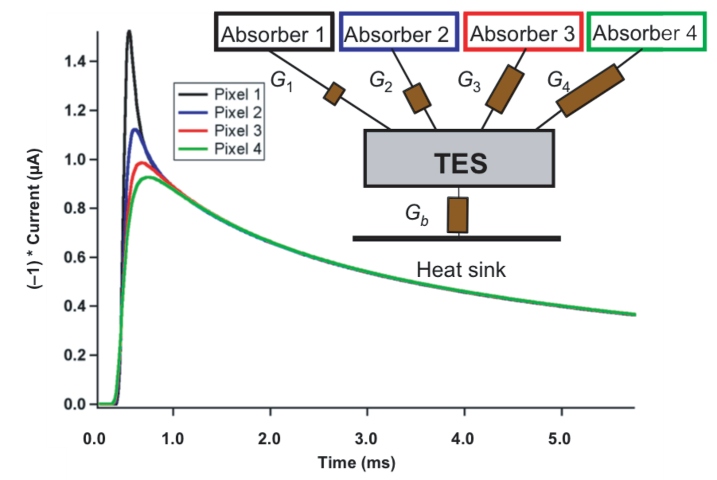
Recent Extended Array Development

We have modified our successful position-sensitive TES design [4] to one that can meet the baseline requirements of the XMS extended array, which call for a significantly larger areal coverage per TES (e.g., 4 x 600 □m pixels per TES as compared to 4 x 250 □m pixels in past work).

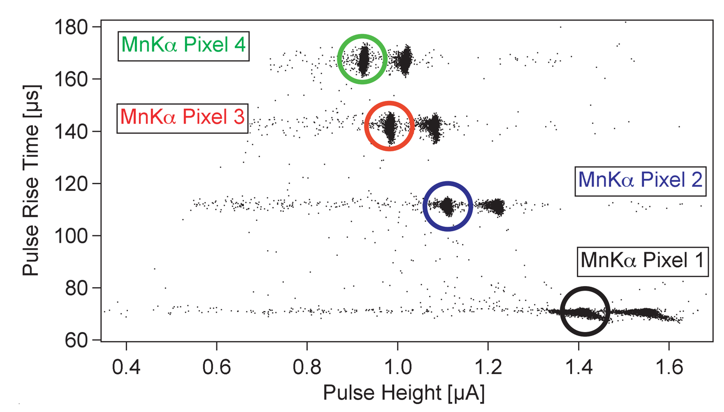


Backside images looking through the nitride membrane. ***Top:*** *Hydra with four 600 □m pixels – the baseline design for the XMS extended array.* ***Bottom:*** *nine 300 □m pixels.*





(Inset) A model of a position-sensitive TES (hydra) in which four pixels are formed from four absorbers and a single TES. (Graph) 6 keV pulses measured experimentally by such a device. The absorbers are each connected to the TES with a different thermal link, G, so x-ray events in the four absorbers produce different pulse shapes.



Left: *Analysis of the pulse height and shape yields the energy of the photon and tells which absorber the x-ray impacted. Preliminary results indicate □E□22 eV FWHM; this should be improved to <15 eV.*

References

[1] S.R. Bandler et al., *J. of Low Temp. Phys.* **151**, 400-405 (2008).
[2] N. Iyomoto et al., Appl. Phys. Lett. **92**, 013508–013510 (2008).
[3] C.A. Kilbourne et al., *Proc. SPIE* **7011**, 701104-701107 (2008).
[4] S. J. Smith et al., *Proc. SPIE* **7011**, 701126-701134 (2008).